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FABRICATION TECHNIQUES FOR FIBER OPTIC FIRE CONTROL ELEMENTS

April 1975

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Manufacturing Technology Directorate

FRANKFORD ARSENAL · U.S. ARMY ARMAMENT COMMAND · PHILADELPHIA, PENNSYLVANIA 19137

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--      PROCEDURES FOR THE PROCESSING OF FIBER OPTIC BLANKS (PLANO-PLANO
--      SURFACES) AND FIBER OPTIC FACEPLATES (PLANO CONVEX AND PLANO-
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This project has been accomplished as part of the USA MM&T program which has as its objective the timely establishment of manufacturing process techniques or equipment to insure the efficient production of current or future defense materials.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the results of a project which was conducted to establish improved manufacturing methods and procedures for the processing of fiber optic blanks (plano-plano surfaces) and fiber optic faceplates (plano convex and plano-concave surfaces). Conventional processes for polishing glass frequently produce scratches, pits, and other defects in fiber optic elements. The fiber optic elements were successfully manufactured using the described processes.

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18. SUPPLEMENTARY NOTES (Cont'd)

The author wishes to acknowledge the assistance of Mr. Frank Sama of the Applied Technology Directorate of Frankford Arsenal who accomplished accomplished all of the grinding and polishing of the fiber optic elements.

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GLOSSARY

Boule - A pressed, fused assembly of optical fibers that are processed to form vacuum tight fiber optics fused plates or cones.

Coating or Cladding - The low refractive index material that sheaths the fiber core and serves to provide optical insulation and protection to the total reflection interface. Sometimes referred to as "cladding". Generally the thickness of the coating is not required to exceed $\lambda/4$ to $\lambda/2$.

Core - The high refractive index central material of a fiber along which light is propagated.

Effective N.A. - Always less than nominal N.A. (numerical aperture) since either the resolving power or transmission must drop drastically near the nominal N.A. (numerical aperture). One must specify carefully a desired operational result in order to define an effective N.A. (numerical aperture).

Fiber-multi-multi-fiber - A fiber configuration that consists of a multitude of smaller diameter fibers. Multiple fibers have made possible the availability of very small fibers that are capable of high resolution and can be easily handled.

Fiber Optics - The art of active and passive guidance of optical radiation (rays and waveguide modes) along transparent fibers through predetermined paths. Single fibers or an assembly of fibers have the following principle advantages over other optical components:

(a) Ability to transport light along flexible axes, thus enabling visualization of areas inaccessible to direct observation or modifying the shape of an image surface.

(b) Ability to accept and transport light at large angles (N.A. >1) with high photometric efficiency.

(c) Ability to act as an active guide (light emitter) as well as a light guide e.g. scintillating and lasing fibers.

(d) Ability to propagate and/or couple discrete waveguide modes.

Glass-coated glass fiber - Glass fiber core with coating of low refractive index glass.

Mean transmission length or mean length - Transmission of light of wavelength at angle varies as

$$I = I_o e^{-\alpha L}$$

where I = Light intensity at $L = 0$
I_o = Light intensity at L
L = length of fiber
α = effective absorption coefficient.
Since L is a function of Θ_1, the integrated transmission doesn't fall off as a simple exponential.

Mosaic construction - A construction in which fibers are grouped and regrouped to build up an area. This usually results in some degree of imperfection at the boundaries of the subgroup. When this boundary condition becomes very noticeable it is called chicken wire.

Nominal N.A. (Numerical Aperture) - $N.A. = \eta_1^2 \quad \eta_2^2$

η_1 = index of refraction of core material.

η_2 = index of refraction of cladding material.

Numerical Aperture or N.A. - Sine of the acceptance half angle, sine of the filled half angle.

INTRODUCTION

The entire theory of fiber optics hinges on the principle of total internal reflection. This principle allows the fiber to propagate light down the length of the fiber with very little light loss. An optical fiber is made up of two types of glass, Figure 1. The core material has a higher refractive index than the cladding. This difference in refractive indicies produces total internal reflection in optical fibers.

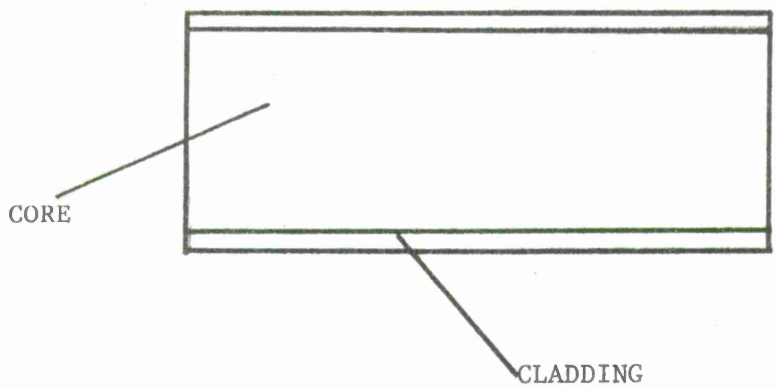


Figure 1. Cross Section of a Single Fiber

Many glass fiber optic filaments are fused together into a plate or a mosaic, having many parallel light channels. One of the major uses for fiber optic plates or mosaics is as input and output windows for image intensifier tubes. In these applications, the basic function of the fiber optics is to transport an image into or out of the vacuum enclosure, but fiber optics may additionally be used for field flattening, distrotion correction, ambient light suppression, or control of angular distribution.

THEORY

Since applications for a single fiber are more theoretical than practical, a large number of fibers (from 100 to 1,000,000) are fused together to form a plate or a mosaic.

However, to see how a fiber transmits light it is simpler to look at a single fiber.

The entire theory of fiber optics hinges on the principle of total internal reflection. This principle allows the fiber to propogate light down the length of the fiber with very little loss.

Two conditions must be met for total internal reflection to occur:

1. The light ray travels from a material with a higher index of refraction to a material with a lower index of refraction (The core of an optical fiber must have a higher refractive index than the cladding).

2. The incident light ray must fall within the angle of acceptance. This angle of acceptance is given by:

$$\sin \Theta_1 = \frac{\eta_1{}^2 - \eta_2{}^2}{\eta_3}$$

Where η_1 = index of refraction of core material

η_2 = index of refraction of cladding material

η_3 = index of refraction of the surrounding medium (usually air) See Figure 2.

Fiber optic plates or mosaics do not have any magnifying properties, however, they do transmit images. For this reason both the entrance and exit surfaces must be highly polished.

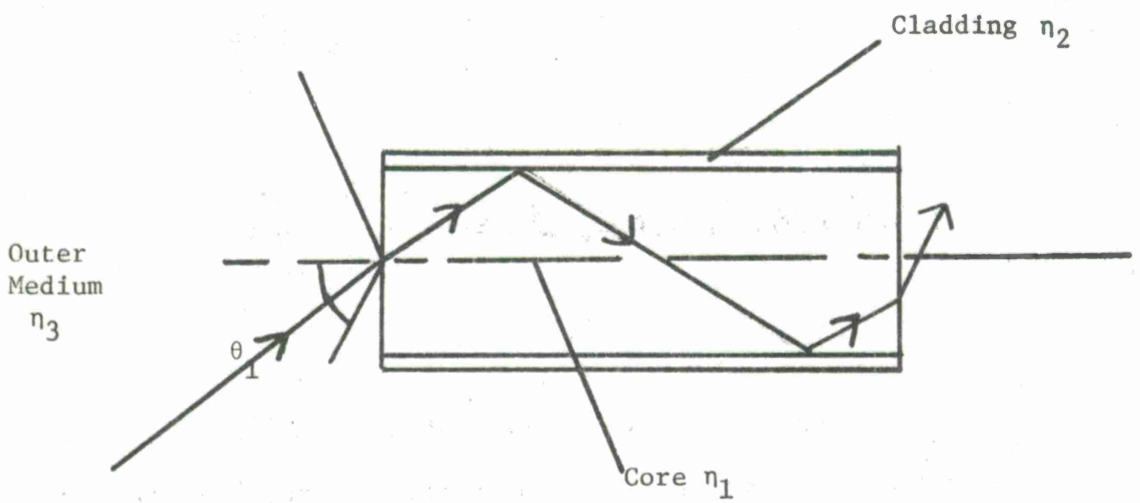


Figure 2. Path of a Light Ray Inside a Fiber Optic Filament

PROCEDURE

This report summarizes the results of two projects (6727187 and 6737187) which were conducted to establish improved manufacturing methods and procedures for the processing of fiber optic blanks (plano-plano surfaces) and fiber optic faceplates (plano-convex surfaces and plano-concave surfaces). Conventional polishing processes frequently produce scratches, pits and other defects in fiber optic elements.

Plano-plano surfaces were shaped, ground, and polished under project 6727187. Plano-concave and plano-convex surfaces were shaped, ground, and polished under project 6737187.

Fiber optic boules were purchased from the Electro-Optics Division of the Bendix Corporation. Figure 3 shows a fiber optic boule and two fiber optic blanks. A fiber optic boule is also shown in Figures 4 and 5. These boules were cut into the thicknesses required and then shaped, ground and polished.

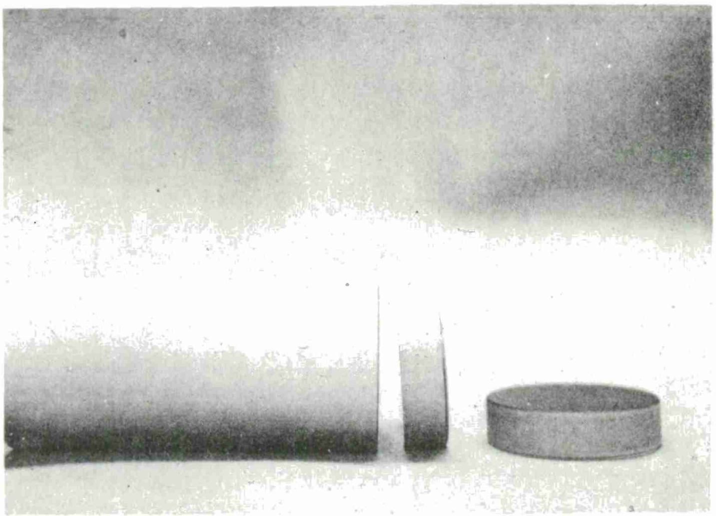


Figure 3. A Fused Fiber Optic Boule

The boules were composed of fused optical fibers, 6 microns in diameter. The length of each boule was approximately three inches; their diameters were 1.4 inches. Before sawing, each boule was checked for internal breaks in the fibers by placing it in front of a light bulb and visually examining it for internal breaks.

A. Plano-Plano Surfaces

1. Sawing

The sawing operation was done on a Hardringe Milling Machine, Model TM. The saw blade (#F 7640) used was made by the Walter R. Falck Company of Wynnewood, Pa. It had the following characteristics:

D = 120 grit
A = 100 concentration
    1/8 amount of diamond
Diameter = six inches
Thickness = .035 inches

The revolutions per minute of the saw blade during cutting was approximately 1950. The travel of the saw table was one inch per minute. The coolant used was one pint of Quaker Grind Oil Mix #101 to ten gallons of water. Two coolant feed lines were used during sawing.

The fiber optic boule was prepared for sawing by fastening it to a rectangular piece of plate glass (1/2 inch thick). The plate glass was placed on a hot plate and heated to approximately 275^{O}F. Stickum wax was applied to the central portion of the plate glass. The plate was removed from the hot plate. The fiber optic boule was placed in the pool of melted stickum wax. One face of the boule was placed flush with an edge of the plate glass. A strip of glass (approximately 1/2" by 1/2" by 3") was placed on each side of the boule to act as supports during the sawing. The assembly was set aside to cool before sawing. (See Figure 4).

Every saw cut was made perpendicular to the direction of the fibers (See Figure 5). Six blanks were cut from the fiber optic boules to be made into plano-plano surfaces. After sawing each blank was .475 inches thick. The finished thickness of the plano-plano fiber optic surface was 0.365 $\pm$ 0.005 inches. The excess material (0.110 inches) was removed during the rough grinding, fine grinding, and polishing steps.

After sawing, the blanks were placed in a vapor degreaser (Detrex Degreaser, Model No. 2D-500). The vapors of trichloroethylene removed all the stickum wax from the fiber optic blanks.

2. Rough Grinding

A metal parallel plate was placed on a hot plate and heated to approximately 275^{O}F. Stickum wax was applied to the blocking plate. The fiber optic blanks were placed in the melted stickum wax. The blanks were pressed firmly onto the blocking plate to remove excess stickum wax and

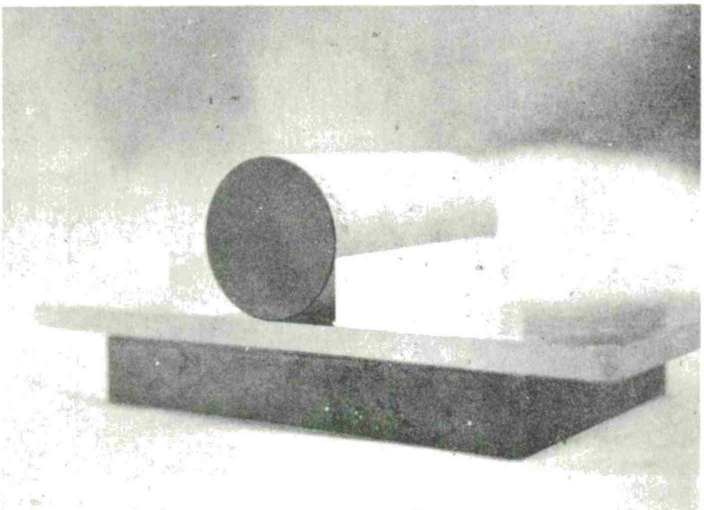


Figure 4. Fiber Optic Boule Assembly Ready for Sawing

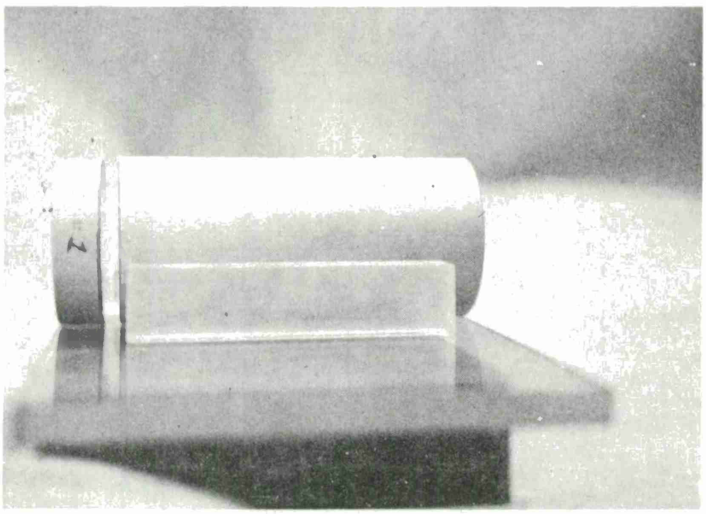


Figure 5. Example of Fiber Optic Boule Assembly After One Saw Cut

to obtain a good seating position on the blocking plate. Figure 6 shows the configuration of the fiber optic blanks on the blocking plate. The six blanks that were polished are on the outside with a dummy blank in the center.

The fiber optic blanks were rough ground on a Blanchard Machine, Model No. 11. The table speed of the Blanchard Machine was approximately 15 revolutions per minute. A #240 grit diamond wheel was used. The feed was set at setting #4, the slowest possible setting. A slow grinding speed was used to reduce chipping and flaking of the edges of the fiber optic blanks.

The amount of material removed from the first side of the fiber optic blanks during rough grinding was .045 inches.

The blanks were removed from the blocking tool by placing it on a hot plate to melt the stickum wax. The blanks were then placed in a vapor degreaser using trichloroethylene. The blanks were then cleaned with naptha solvent and cheesecloth.

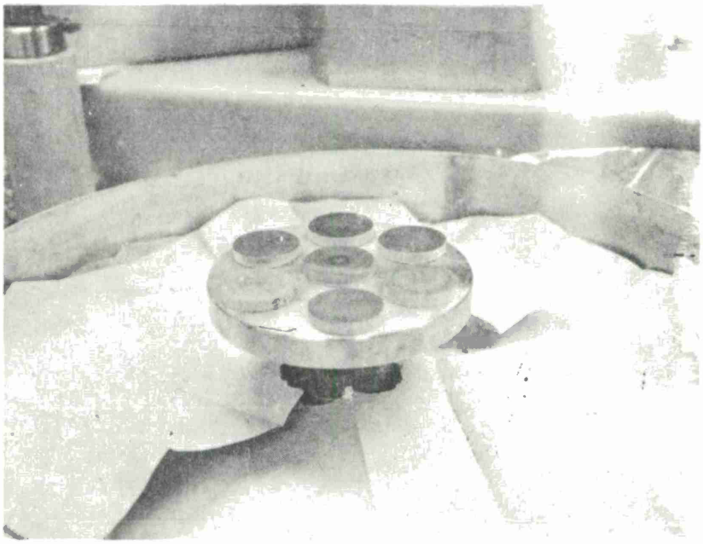


Figure 6. Configuration of Plano-Plano Fiber Optic Surfaces on the Blocking Plate

To rough grind the second side of the blanks, the metal blocking plate was again heated to approximately 275°F. Beeswax was used to cement the blanks to the blocking plate instead of stickum wax. The same prcedure for rough grinding the first side of blanks was used for the second side.

The amount of material removed from the second side of the blanks was .045 inches. After rough grinding the thickness of the fiber optic blanks was .385 inches.

After the second side was rough ground, the blanks were removed from the blocking plate by placing it on a hot plate to melt the beeswax. The blanks were then placed in a vapor degreaser and cleaned with a naptha solvent and cheesecloth.

3. Beveling

The edges of the fiber optic blanks were beveled to protect them against chipping and breakage during the fine grinding and polishing steps. A standard 45^{o} bevel was used (See Table 2). The face width of the bevel was .030" $\pm$ .005" (See Figure 7).

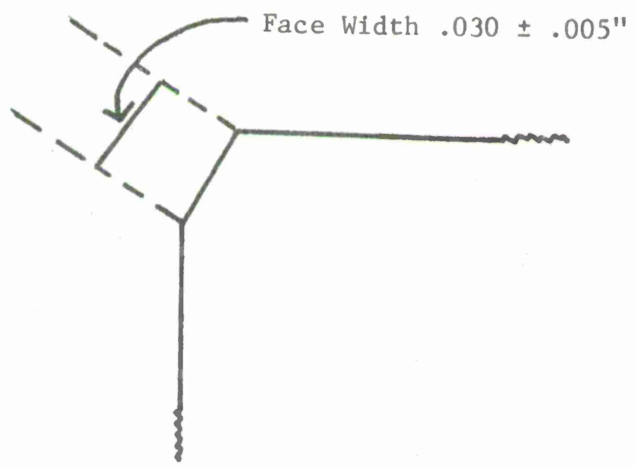


Figure 7. Face Width of the Bevel

When the bevel was put on, it was made .005" larger than the specified face width. This excess material was removed during the fine grinding and polishing steps so that the dimension of the face width fell into the tolerance range for the finished fiber optic element.

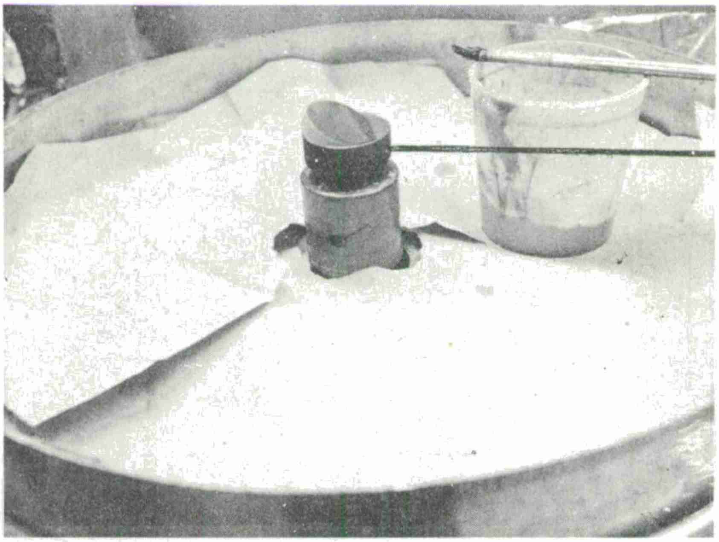
The radius of the beveling tool was obtained from the following formula:

Tool Radius = diameter of flat X Sine of the bevel angle.

For this example:

Tool Radius = 1.400" X Sine 45° (0.707) = 0.909 inches

Figure 8 shows the beveling tool used.



Beveling Tool

Figure 8. Tool Used for Beveling the Edges of the Fiber Optic Blanks

The abrasive used for beveling was W-7 garnet. The spindle speed of the Strausbaugh Polishing Machine Model 6Y was approximately 120 rpms.

4. Fine Grinding and Polishing

A metal blocking plate (5 inches in diameter and 0.636 inches thick) was heated on a hot plate such that beeswax would melt upon application. The beeswax was spread evenly on the blocking plate. The fiber optic blanks were arranged in the pattern shown in Figure 6. The blanks were firmly pressed down to seat them on the blocking plate. The blocking plate was then set aside to cool.

The fine grinding operation was accomplished on a Strausbaugh Polishing Machine Model 6Y using a metal grinding tool and W-7 garnet as the abrasive. Figure 9 shows the metal tool used to fine grind the plano-plano fiber optic surfaces.

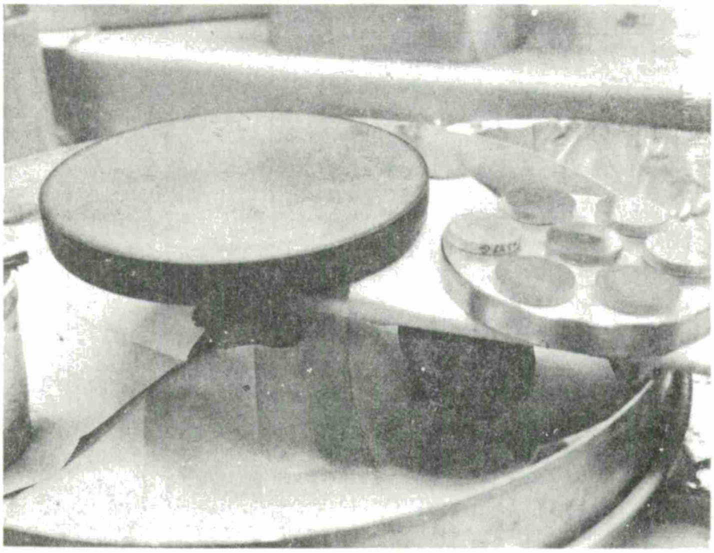


Figure 9. Metal Grinding Tool for Fine Grinding Plano-Plano Surfaces

The speed of the grinding tool was 140 rpm. The fine grinding operation continues until the pits and other surface irregularities are removed. The amount of material removed from the first side was 0.007 inches.

To polish the first side of the blanks a plane pitch polishing lap was used with barnsite (manufactured by the Rare Earth Division of the American Potash and Chemical Corp.) as the polishing medium and water. The composition of the pitch polishing lap was three parts of burgundy #1 and one part of burgundy #2 (both burgundy #1 and burgundy #2 are manufactured by Stephenson Bros. Inc.). Figure 10 shows the pitch polishing lap that was used. The spindle speed was 100 rpms. The barnsite mixture was applied to the specimens with a camel hair brush. Polishing continued until the surface was free of any grinding pits or scratches. Surface flatness was measured by using a flat test glass. The blanks were polished to three rings or less as measured on the test glass.

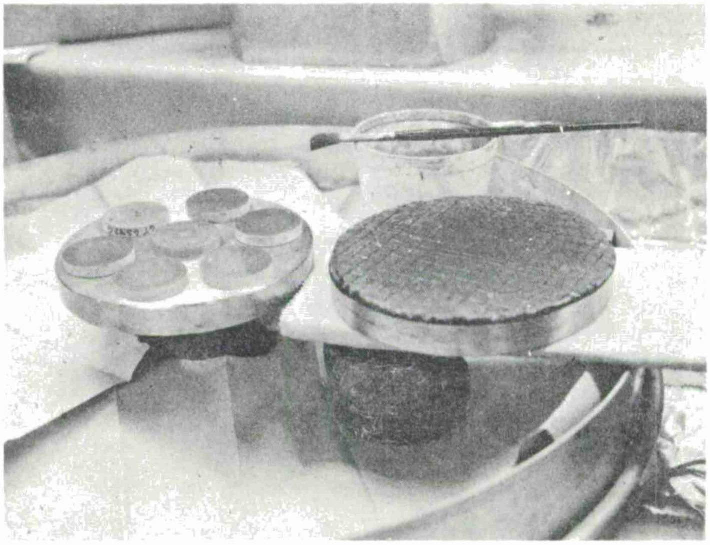


Figure 10. Pitch Polishing Lap for Polishing Plano-Plano Surfaces

To polish the second side of the blanks, they must be transferred to another metal blocking plate. This second blocking plate was heated on a hot plate. The plate was hot enough to melt a second side wax upon application. Newspaper was placed on the melted wax. Excess second side wax was pressed out from between the newspaper and the metal plate. More second side wax was applied to the surface of the newspaper. The first metal plate with the fiber optic blanks was placed directly above the second metal plate with the finished side of the fiber optic blanks in contact with the second side wax. This assembly was set aside to cool. Upon sufficient cooling the assembly was placed on a hot plate as shown in Figure 11 and heated slowly. As soon as the beeswax on the first blocking plate softens, it is removed using the method depicted in Figure 11. The fiber optic blanks remain firmly fastened with second side wax to the second blocking plate.

Beeswax that remained on the exposed faces of the fiber optic blanks was removed using a razor blade and/or lukewarm, soapy water and a stiff-bristled brush. Care was taken so that the water temperature was below the melting point of the second side wax (approximately 200°F.).

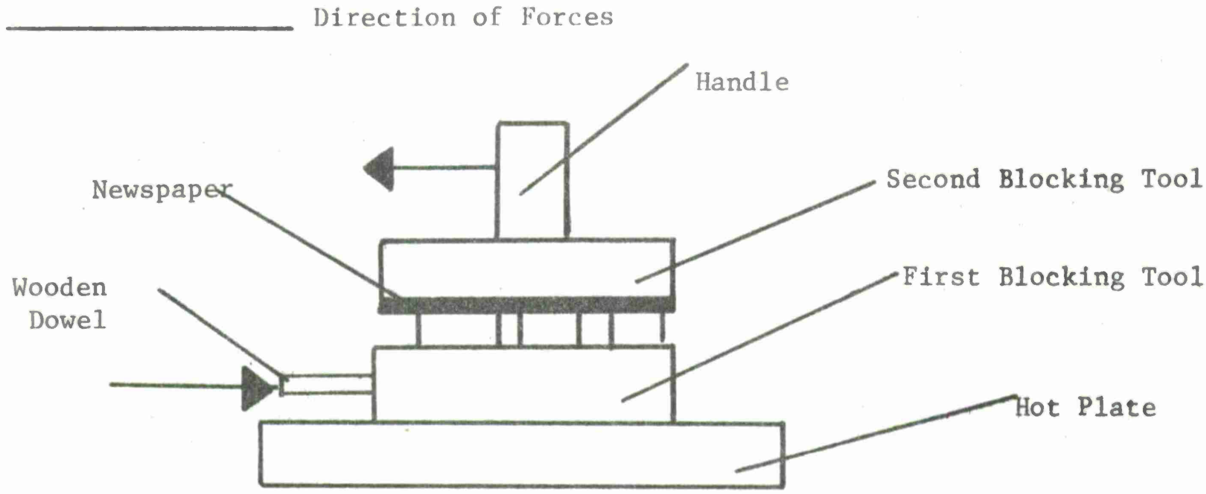


Figure 11. Block Transfer Technique

The fine grinding operation on the second side of the blanks was done using the same procedure as was used to fine grind the first side. The amount of material removed from the second side was 0.008".

The same pitch polisher was used to polish the second side that was used to polish the first side. The same procedure as listed above was followed. Polishing continued until the surface was free of any grinding pits or scratches. Surface flatness was measured by using a flat test glass. The blanks were polished to three rings or less as measured on the test glass.

After polishing, the metal plate was placed on a hot plate. When the second side wax was soft enough to slide, the newspaper with the fiber optic blanks was pulled completely off the metal plate.

The finished fiber optic plates were cleaned in a vapor degreaser using trichloroethylene to remove any remaining traces of wax. The fiber optic plates were then cleaned with 95% ethyl alcohol (190 proof).

Table 1 lists the specifications and the evaluation of five fiber optic elements (plano-plano). Most of the specifications were met. An error by the operator resulted in the bevel not meeting the specification. The poor optical quality of sample #5 was due to imperfections in the material and not to shop practice techniques. All of the five samples failed the 80/50 scratch and dig standard.

Table 1. Physical and Optical Measurements of Plano Fiber Optic Fused Plates

PARAMETER	SPECIFICATION		#1	#2	#3	#4	#5
Diameter	1.375 ± .002 inch		1.3750"	1.3750"	1.3750"	1.3750"	1.3749"
Thickness	.365 ± .005 inch		.3647"	.3654"	.3652"	.3643"	.3645"
Parallelism	.002 inch		.0008"	.0004"	.0004"	.0007"	.0004"
Edge Bevels	.030 ± .005" X45°		.0113"	.0108"	.0112"	.0123"	.0125"
Flatness	3 rings or better		2	2	2	2	2
Collimated Transmission	65%		68%	68%	68%	68%	64%
Resolution	100 Lp/mm		102	102	110	110	64
Surface Structure							
Haze, Crazing	None		None	None	None	None	None
Cracks, Fractures	None		None	None	None	None	Broken fibers defects along multiple fiber perimeters.
Scratches, Digs	MIL-O-13830A	Surface (1)	5/80	4/25	6/55	2/20	4/180
# per sq. inch **		Surface (2)	5/75	4/20	2/40	0/30	2/10
Approximate	80/50	Surface (1)	50/48	605/20	500/40	100/20	300/65
Limiting No.		Surface (2)	350/45	875/20	120/35	80/30	300/20

** Based on digs larger than 80 microns (dig number = 8), scratches longer than 800 microns (scratch number = 80)

Table 2 lists the specifications for six more fiber optic elements (plano-plano). These elements were polished by modifying the polishing process slightly and by switching to a softer polishing lap. All of the six plano-plano elements met the specifications. The Table also shows an evaluation done on six plano-plano fiber optic elements purchased from the Bendix Mosaic Corporation. The larger radius for the Frankford Arsenal samples was requested by the optical shop because many of the tools for that diameter were already in existence.

B. Plano-Concave Surfaces

Following the successful manufacturing of plano-plano fiber optic surfaces, plano-concave fiber optic faceplates were made. Two different radii, -0.689 and -1.251 inches, were polished. Figure 12 shows the configuration of the plano-concave faceplates. Two faceplates of each radius were manufactured.

Figure 12. Plano-Concave Fiber Optic Faceplates

The major differences in polishing plano-plano surfaces and plano-concave surfaces are:

1. The need for a step to generate the radius of curvature.
2. Since the radii were sharp in relation to the diameter of the piece, they were polished singularly.
3. The composition of the pitch polisher was changed from three parts of burgundy #1 and one part of burgundy #2 to two parts of roofing pitch and 1 part of rosin.

The faceplates were manufactured according to the specifications listed in Table 3.

Table 2. Evaluation & Comparison of Plano-Plano Fiber Optic Surfaces

PARAMETER	SPECIFICATION	FRANKFORD ARSENAL 1	2	3	4	5	6	BENDIX 1	2	3	4	5	6
1. Diameter (inches)	1.375 ± 0.002	1.339	1.339	1.400	1.400	1.400	1.401	1.375	1.375	1.375	1.375	1.375	1.375
2. Thickness (Inches)	0.365 ± 0.005	0.369	0.369	0.369	0.369	0.369	0.370	0.368	0.368	0.368	0.368	0.368	0.368
3. Parallelism(Inches)	0.002	0.0005	0.0005	0.0002	0.0004	0.0003	0.0004	0.0003	0.0005	0.0003	0.0009	0.004	0.004
4. Edge Bevel(Inches)	0.030 ± 0.005 X 45°	0.029	0.029	0.028	0.028	0.027	0.031	0.018	0.020	0.018	0.018	0.017	0.019
5. Flatness	3 rings or better TOP BOTTOM	1/2 1	3/4 2	1/2 1	1 2	1/2 1	2 2	2 2	2 2	2 2	2 2	2 2	2 2
6. Resolution(LP/mm)	> 100	102	102	102	102	102	102	114	114	114	114	114	114
7. Fiber Size (Microns)	6.0 nominal	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
8. Transmission (%)	65 minimum	70	70	70	70	70	69	69	70	70	69	69	70
9. Multi-fiber Shading*	(%) Average Transmission ±3.0	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
10. Banding (%)*	Average Transmission ± 3.0	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
11. Frame Run Out(Inch)*	0.010 maximum	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
12. Gross Distortion (Inch) *	0.004 maximum	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
13. Shear (Inch) *	0.001 maximum	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
14. Chicken Wire <12 microns *	No Limit	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
15. Blemishes (Inch)	TOTAL 5: 0.0015 -0.0025 1: 0.0025 -0.0075 0: > 0.0075	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
16. Pits	One/Multi-multifiber	None	None	None	None	None	None	None	None	None	None	None	None
17. Cracks	None	None	None	None	None	None	None	None	None	None	None	None	None
18. Chips	None	None	None	None	None	None	None	None	None	None	None	None	None
19. Scratches/Digs	80/50 MIL-O-13830A	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed

*See DEFINITIONS on next page.

Table 2. Evaluation & Comparison of Plano-
Plano Fiber Optic Surfaces

* DEFINITIONS

Multi-fiber shading - A small area (one or more multifibers) that is lighter or darker than the average faceplate transmission. The deviation from the average transmission shall not exceed ± 3%.

Banding - A large shaded area (generally in bands across the faceplate) that is lighter or darker than the average faceplate transmission. The deviation from the average transmission shall not exceed ± 3%.

Frame Run Out - A uniform displacement of the fibers from the normal axis. This can occur when the top and bottom surfaces of an individual plate is cut parallel but on a bias with respect to the fiber axis.

Gross Distortion - The apparent bending of a straight line when focused on one side of a fiber plate and viewed from the opposite side. It does not include a uniform axial tilt of the fibers from surface to surface of a fiber optic plate which causes a uniform displacement of the line.

Shear Distortion - An offset of a segment of the image of a straight line relative to the original line. The offset can be angularly displaced parallel to the original line. When viewing the image, it would appear as below:

Chicken Wire (Multifiber Boundary) - A regular pattern or enhanced multi-multi fiber boundaries (pattern of non-transmitting lines). Chicken wire less than 12 microns width is acceptable.

Blemishes (Dead Spots) - Any area with transmission less than 70% of average diffuse transmission of the plate. Irregular shaped areas shall be treated as circular areas of equivalent size. Non-transmitting areas that are separated by less than the distance of the major axis of the larger blemish shall be considered as one blemish with a size equal to the sum of the maximum dimensions of the two plus the separation between them.

Table 3. Physical and Optical Specifications of Fiber Optic Faceplates (Plano-Concave)

PARAMETER	SPECIFICATION	#1	#2
Diameter (inches)	1.4 ± 0.002	1.400	1.400
Thickness (inches)	0.42 ± 0.005	0.4201	0.4199
Radius of curvature (inches)	0.6875 ± 0.002	0.6899	0.6899
Flatness (bottom surface)	3 rings or better	< 3 rings	< 3 rings
Blemishes	NONE	NONE	NONE
Chips	NONE	NONE	NONE
Cracks	NONE	NONE	NONE
Pits	one/multi-multi fiber	NONE	NONE
Scratches/Digs	MIL-O-13830A 80/50	40/10	40/10

PARAMETER	SPECIFICATION	#3	#4
Diameter (inches)	1.4 ± 0.002	1.400	1.400
Thickness (inches)	0.242 ± 0.005	0.245	0.244
Radius of curvature (inches)	1.250 ± 0.002	1.250	1.250
Flatness (bottom surface)	3 rings or better	< 3 rings	< 3rings
Blemishes	NONE	NONE	NONE
Chips	NONE	NONE	NONE
Cracks	NONE	NONE	NONE
Pits	one/multi-multi fiber	NONE	NONE
Scratches/Digs	MIL-O-13830A 80/50	40/10	40/40

1. Sawing, Rough Grinding, Beveling.

The sawing, rough grinding, and beveling steps were the same as for the plano-plano surfaces listed above (A-1, A-2, and A-3).

2. Curve Generation

Following the beveling step, the radii of -0.689 and -1.251 inches were generated on the fiber optic blanks. Two of each radius was done. The curve generation was accomplished on a Desenberg Curve Generator, Model #5.

A metal holder was machined to fit the diameter of the fiber optic blanks (1.400 inches). A #240 grit diamond lap was used as the cutting tool. The diamond lap was fed into the fiber optic blank very slowly in order to reduce the possibility of fracturing the fiber optic bundles. The coolant used was 1/2 pint of Quaket Grind #101 to ten (10) gallons of water.

The operation continued until the approximate center thickness of the fiber optic faceplate was reached. An excess of material was left on the center thickness to be removed during the fine grinding and polishing steps. A spherometer was used to check the curvature of the faceplate. The faceplate was generated so that the spherometer would read 0.001 inch lower than the radius of the test glass that was used.

3. Fine Grinding and Polishing

Since the radii to be fine ground and polished were sharp in relation to the diameter of the piece, it was decided that the fiber optics should be polished singularly instead of on a multiple block.

Sealing wax (manufactured by Stephenson Bros. Inc.) was used to hold the faceplate to a blocking tool during polishing. The faceplates were heated on a hot plate to approximately 250^{o}F. The black sealing wax was heated in an electric heating pot to 175^{o}F. The heated sealing wax was applied to the faceplate, and pressed into a brass mold made for the diameter of the faceplate and the depth of the black sealing wax required. See Figure 13. The plano side of the faceplate was polished first.

The blocking tool was a thin disc with a 1/8 inch hole in the center of one side. The blocking tool was heated on a hot plate. The faceplate with the black sealing wax was placed in contact with the hot blocking tool.

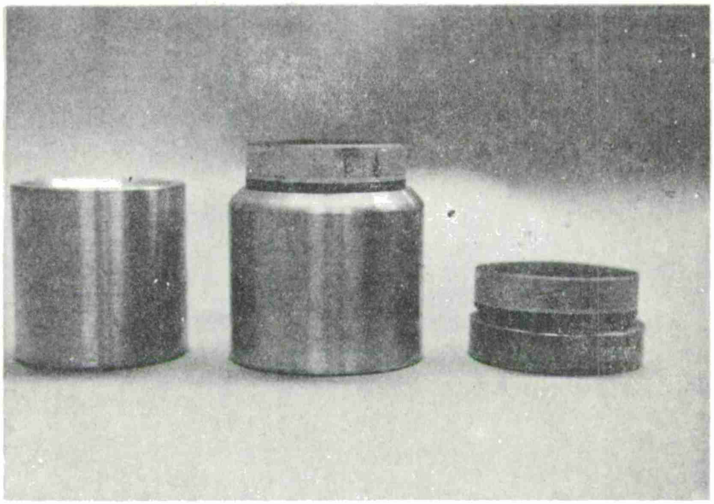


Figure 13. Backing Up Fiber Optic Faceplates Using Black Sealing Wax

The plano side of the faceplate was polished using the methods listed in A-4. The only exception was that the faceplates were polished singularly instead of in a multiple faceplate configuration.

After the plano side was polished, the faceplates with the black sealing wax attached were placed in a refrigerator. This caused the faceplates to separate themselves from the black sealing wax. The faceplates were then cleaned with alcohol and cheesecloth.

To polish the concave side of the faceplate, the faceplate was backed up using black sealing wax as listed above. The blocking tool was applied in the same manner also. The only difference being that the black sealing wax was applied to the finished plano side.

Fine grinding the faceplates was done on a Strausbaugh Polishing Machine Model 6Y. The metal grinding tools for the -0.689 inch radius and the -1.251 inch radius are shown in Figures 14 and 15 respectively. The abrasive used was #1600 emery. The faceplates were ground until the physical measurements specified in Table 3 were met.

The faceplates were also polished on the Strausbaugh Machine Model 6Y. The polishers for the two radii -0.689 inches and -1.251 inches are shown in Figures 14 and 15 respectively. The polishing medium used was

Barnsite #924 and water. The composition of the polishing lap was 2 parts of roofing pitch and 1 part of rosin. Polishing continued until the surface was free of any grinding pits or scratches. The faceplates were polished to three rings or less as measured on the test glass for that radius.

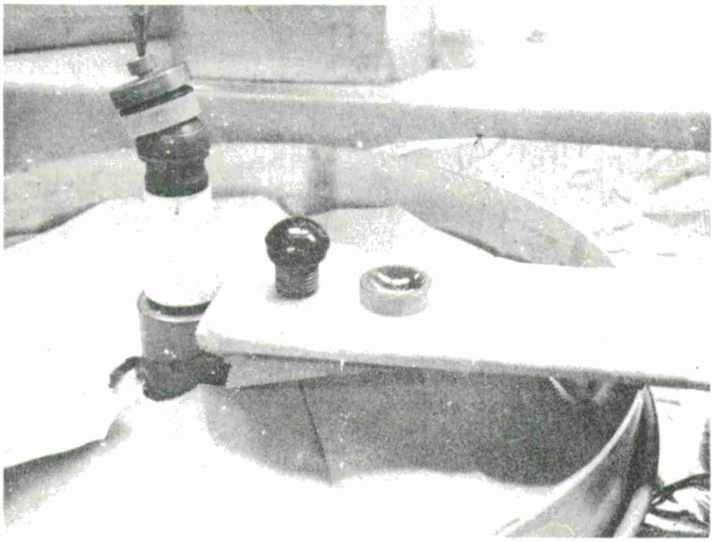


Figure 14. Grinding Tool (On Spindle) and Polisher for -0.689 Inch Radius

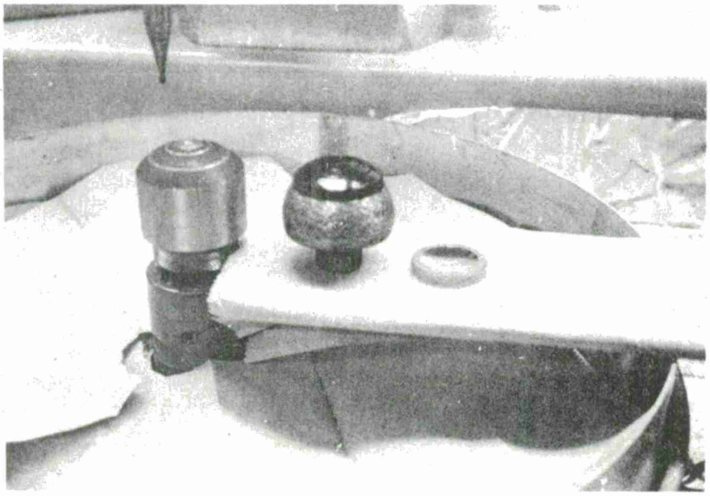


Figure 15. Grinding Tool (On Spindle) and Polisher for -1.251 Inch Radius

After polishing, the faceplates were placed in a refrigerator to remove the black sealing wax. The fiber optic faceplates were then cleaned with 95% alcohol (190 proof) and cheesecloth. Table 3 lists the specifications and evaluation of four fiber optic elements (plano-concave). All the samples met the specifications.

C. Plano-Convex Surfaces

Plano-convex fiber optic surfaces were the third form of fiber optic surfaces to be manufactured. Two different radii, +1.251 and +4.500 inches, were polished. Figure 16 shows the configuration of the plano-convex surfaces. Two pieces of each radius were manufactured.

The major differences in polishing plano-plano surfaces and plano-convex surfaces are:

1. The need for a step to generate the radius of curvature.
2. Since the radii were sharp in relation to the diameter of the piece, they were polished singularly.
3. The composition of the pitch polisher was changed from three parts of burgundy #1 and one part of burgundy #2 to two parts of roofing pitch and one part of rosin.

There were no major differences between polishing plano-concave and plano-convex surfaces.

The pieces were manufactured according to the specifications listed in Table 4.

1. Sawing, Rough Grinding, Beveling.

The sawing, rough grinding, and beveling steps were the same as for the plano-plano surfaces listed above (A-1, A-2, and A-3).

2. Curve Generation

The curve generation on the fiber optic faceplates was the same as described in section B-1. The only difference was that instead of a concave radius a convex radius of curvature was generated. The two radii generated were +1.251 inches and +4.505 inches.

3. Fine Grinding and Polishing

Since the radii to be fine ground and polished were sharp in relation to the diameter of the piece, it was decided that the fiber optics should be polished singularly instead of on a multiple block.

Table 4. Physical and Optical Specifications of Fiber Optic Faceplates (Plano-Convex)

PARAMETER	SPECIFICATION #1	SPECIFICATION #2
Diameter (inches)	1.400 ± 0.002	1.400 ± 0.002
Thickness (inches)	0.365 ± 0.005	0.365 ± 0.005
Radius of Curvature (inches)	1.251 ± 0.002	4.505 ± 0.002
Flatness (plano-surface)	3 rings or better	3 rings or better
Blemishes	None	None
Chips	None	None
Cracks	None	None
Pits	one multi-multi fiber	one multi-multi fiber
Scratch/Dig MIL-O-13830A	80/50	80/50

R = +1.251　　　　　　　　R = +4.500

Figure 16. Plano-Convex Fiber Optic Surfaces

A brass mold was made for the diameter of the faceplate and the depth of black sealing wax required. The sealing wax was used to hold the faceplate to a blocking tool during polishing. The faceplates were heated on a hot plate to approximately 250°F. The black sealing wax was heated in an electric heating pot to 175°F. The heated sealing wax was applied to the face plate and pressed into the mold to form the wax into the shape of the mold. See Figure 13. The plano side of the faceplate was polished first. The blocking tool was a thin disc with a 1/8 inch hole in the center of one side. The blocking tool was heated on a hot plate. The faceplate with the black sealing wax was placed in contact with the hot blocking tool.

The plano side of the faceplate was polished using the methods listed in section A-4. The only exception is that the faceplates were polished singularly instead of on a multiple block.

After the plano side was polished, the faceplates were placed in a refrigerator to remove the black sealing wax.

To polish the convex side of the faceplate, the faceplate was backed up using black sealing wax as listed above. The blocking tool was applied in the same manner also.

Fine grinding the faceplates was done on a Strausbaugh Polishing Machine. The metal grinding tools for the +1.251 inches and +4.505 inch radii are shown in Figures 17 and 18 respectively. The abrasive used was #1600 emery. The faceplates were ground until the physical measurements specified in Table 4 were met.

The faceplates were also polished on the Strausbaugh Machine. The polishers for the two radii, +1.251 inches and +4.505 inches are shown in Figures 17 and 18 respectively. The polishing medium used was Barnsite #924 and water. The composition of the polishing lap was 2 parts

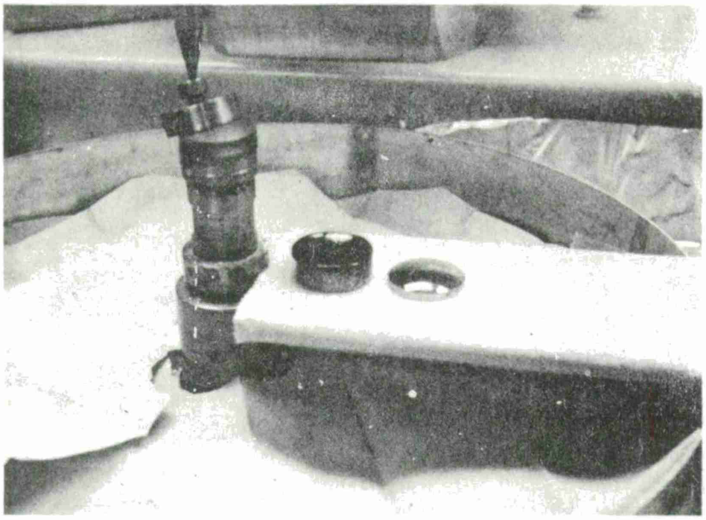


Figure 17. Grinding Tool (On Spindle) and Polisher for +1.251 Inch Radius

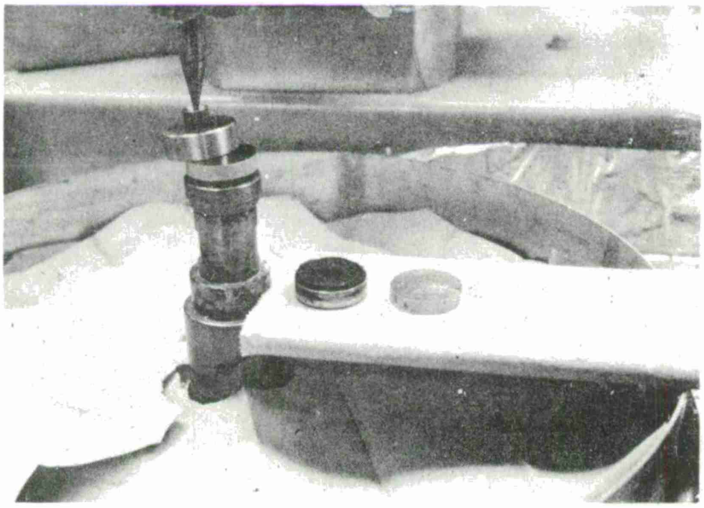


Figure 18. Grinding Tool (On Spindle) and Polisher for +4.505 Inch Radius

of roofing pitch and one part rosin. Polishing continued until the surface was free of any grinding pits or scratches. The faceplates were polished to three rings or less as measured on the test glass for that radius.

After polishing, the faceplates were placed in a refrigerator to remove the black sealing wax. The fiber optic faceplates were then cleaned with 95% alcohol and cheesecloth. Table 4 lists the specifications for four fiber optic elements (plano-convex). Two elements were made in accordance with specification #1 and two in accordance with specification #2. All the samples met the specifications.

SUMMARY/CONCLUSIONS

Conventional processes for polishing glass frequently produce scratches, pits, and other defects in fiber optic elements.

A study was made on various parameters (speeds, grinding compounds, etc.) during sawing, grinding and polishing fiber optic elements. The process described in this report has successfully produced polished fiber optic elements.

The first group of fiber optic elements (plano-plano) polished were scratched badly. All of these samples failed to meet the 80/50 scratch and dig requirements. By modifying the polishing process and switching to a softer polishing lap, plano-plano elements were successfully polished.

No problems were encountered while polishing the plano-concave and the plano-convex elements.

Using the improved manufacturing methods and procedures described in this report, fiber optic elements (plano-plano, plano-concave, and plano-convex) were successfully polished.

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